

# Bringing Human Factor to Business Intelligence

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## Abstract

Starting from Business Intelligence (BI) reference models, this work proposes to extend the multi-dimensional data modeling approach to integrate Human Factors (HF) related dimensions. The overall goal is to promote a fine grain understanding of derived Key Performance Indicators (KPIs) through an enhanced characterization of the operational level of work context. HF research has traditionally approached critical domains and complex socio-technical systems with a chief consideration of human situated action. Grounded on a review of the body of knowledge of the HF field this work proposes the Business Intelligence for Human Factors (BI4HF) framework. It intends to provide guidance on pertinent data identification, collection methods, modeling and integration within a BI project endeavor. BI4HF foundations are introduced and a use case on a manufacturing industry organization is presented. The outcome of the enacted BI project referred in the use case allowed new analytical capabilities regarding newly derived and existing KPIs related to operational performance.

**Keywords:** Human Factors, Data Modelling, Business Intelligence

## 1 Introduction

Business Intelligence (BI) has evolved from the earlier conception of decision support systems and executive information systems on the 80s and 90s originally put forward by Howard Dresner while still in the Gartner Group, to the early days of the current agile, decentralized and data analytics driven orientation brought to focus by Thomas Davenport. Technological evolution and (consequent) data collection and processing capabilities nowadays had allowed to further sustain traditional BI goals as well as move toward the exploitation of new ones. In fact besides the typical focus on historical data reconnaissance and future forecasting, we currently assist to emphasis given to inform present action, based on immediate analysis of high pace generated information. One may indeed, position BI endeavours' outcomes as actionable at different organizational levels. However, formulating KPIs to inform managerial or strategic decisions, will rely on different assumptions and requirements toward data, sources, scope, time horizon and pertinent analytical methods, then when targeting to inform immediate operational action. Such holistic perspective on BI brings two intertwined challenges to existing frameworks: 1) what constitutes a fine level characterization of operational related information, actionable on 2) informing opportunities for immediate or short termed intervention.

In most industries, as those targeted by this work focus, operational level characterization will encompass the acknowledgement of the role of human operator. The present work roots on the existing body of knowledge on the Human Factors field to contribute to furnish BI projects' frameworks. The proposed framework provides fine guidance on the consideration of

dimensions surrounding operational context in the definition and analysis of coherent and articulated KPIs within the overall BI projects' scope. Such aim is accomplished by complementarily extending existing frameworks concepts (e.g.(Kimball & Ross, 2002)) particularly at the information modelling stage to account for Human Factors related data as a significant dimension of analysis. Over the past 40 years, Human Factors research arena has combined numerous disciplines to study and apply physiological and psychological principles on engineering and design of products, tools, processes and systems toward improved adoption and user experience, reduced operative errors and increased safety and productivity (e.g. (Wickens, Lee, Liu, & Gordon-Becker, 2003)).

The present work further discusses a use case to depict the pertinence of the herein proposed framework application on BI project endeavours. The use case shows that it was possible to trace derived KPIs related to minor nonconformities on a production line to the operational level data on (work) process, operator and workplace. Both the solid theoretical grounding of the proposed framework and the discussion of the outcomes achieved through its usage on the reported use case unveil the contribution of this work as one step forward on promoting the accountability of Human Factors on BI projects endeavours.

This paper is organized as follows: Section 2 – Background, addresses Business Intelligence reference frameworks and introduce Human Factors topics considered in the scope of this work; Section 3 delivers the proposed Business Intelligence for Human Factors - BI4HF framework; a use case of BI4HF is presented in section 4 and Section 5 present conclusions and points both limitations and future related research directions.

## 2 Background

### 2.1 Business Intelligence Frameworks

Possibly one of the first definitions of Business Intelligence, and that still sustain nowadays, which to great extent the present work holds accordingly, was that provided by H. P. Luhn in 1958 on IBM Research Journal: “the ability to apprehend the interrelationships of presented facts in such a way as to guide action towards a desired goal.” (Luhn, 1958). From the 60s to present day the underlying concepts, terms, associated methodologies and technologies matured. From Executive Information systems (EIS), Decision Support Systems (DSS) to Knowledge Management Systems (KMM) between the 70s and the 90s, in a more centralized and enterprise level approach, until the current ubiquitous data collection and processing processes, and self-service BI oriented dashboards, as new paradigms on reporting and analytic capabilities (e.g. (Abelló et al., 2013)(Simpson & Burke, 2016)).

Although being BI a data-driven process, a BI endeavour encompasses dedicated organizational and technological processes and resources, with associated skills and tools to derive pertinent and assertive information to support decision and action. Literature abounds in historical BI project failures and in defining Critical Success Factors (CSF) towards BI initiatives (Larson & Chang, 2016).

In the late of 20st century two major frameworks establish the reference toward guidance on BI projects. The Corporate Information Factory (CIF) by Bill Inmon (Inmon, Inmon, Imhoff, & Sousa, 2001) and the Dimensional Modelling (DM) approach by Richard Kimball (Kimball & Ross, 2002) become the references from since on BI projects endeavours. Both develop from data – analysis

demands dyad, to (business) requirements and on (to some extent, classical) data warehouse design, but covering a full range of concerns on BI projects enactment on a domain independent manner. That merit and therefore their pertinence remains even that data warehouse or current alternatives for (big) data storage and analytics are accomplished through state of the art technologies. Among deciding factors regarding which framework to adopt, one have to frame the project in hand against reporting scope and data update/refresh rate and time to analytics availability, project urgency, and adherence with roles envisioned within the framework.

As a natively bottom-up, incremental, and processes oriented approach, Kimball's framework more readily offers possibilities to align with the current tenets of agile project management methodologies for BI projects enactment that pursue expeditious deliveries [agile (and overcome CSFs)].

The current work builds upon Kimball's framework, refer to Figure 1, and therefore it is briefly discussed to frame the actual contribution. This work departs from project management related activities, as well as, associated roles definition. Besides such scope, Kimball's framework mostly addresses the coexistence of three main workflows: 1) technology (infra-structure); 2) data (modelling and ETL processing) and 3) applications (reporting and interaction and analytical capabilities).

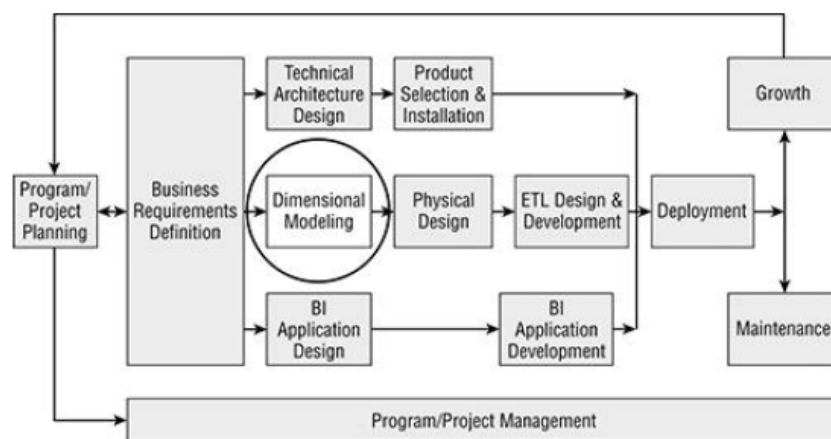


Figure 1- Richard Kimball BI framework, and Multi-dimensional modelling highlight (Kimball & Ross, 2002)

It is indeed on data workflow, that one may find one Kimball's substantial contribution: the Dimensional Modelling (DM) approach to data (warehouse). Although originally grounded on a relational star-schema, the dimensional modelling concept may be revisited independently of the data storage and analytical tools underlying technologies. Conceptually, the DM derived star-schema put forward a central Facts table that brings together business (processes) measures (KPIs) with dimensions of analysis as "peripheral" tables, please refer to Figure 2.

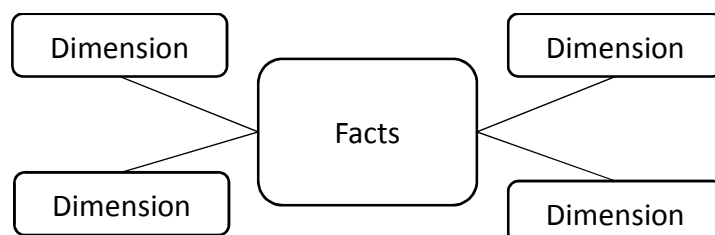


Figure 2 –Multi-dimensional star schema

A classic example is the retail sales domain, referring to sales analysis, where DM is accomplished by a Facts table containing sales measures (e.g. monetary value or number of items) in context of elected dimensions of analysis, typically, Products characteristics/categories, Subsidiary stores and Time. Dimensions embody attributes, those factors that guide analytical purposes, as either aggregators of facts measures, or filtering criteria; as for instance: the analysis of monetary total of sales, of a specific product category (product attribute), on a specific region (a collection of subsidiary stores under a criteria), on the first two quarters ranked through the three last years (year and quarter will be attributes present in time dimension).

As stated, the framework and data DM are domain independent and technology agnostic, and has constituted a reference in BI projects development in a multitude of domains ever since. On this basis and rooted on the DM paradigm, the current work aims to extend guidance on the consideration of dimensions of analysis that may frame business measurements in the realm of Human Factor related elements.

## 2.2 Human Factors

Human Factors and Ergonomics are defined by the International Ergonomics Association as “the scientific discipline concerned with the understanding of interactions among humans and other elements of a (work) system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall (work) system performance”. Given its disciplinary roots HF research, on human work design and evaluation had traditionally heavily relied on qualitative methods, that progressively have being structured, organized and standardized under an umbrella often referred as Human-Centered Design - HCD (or User-Centered Design - UCD) (Lee & Boyle, 2017).

Nevertheless, the state of the art on human operator and human-system interaction models, as well as, design and evaluation methods is better described as a catalogue of techniques, principles and theories, most of them strongly influenced by the domains that fuel them, rather than as a unified theory. Although several taxonomies may be put forward to map them, one may broadly distinguish models and companion methods against their matters into: 1) directed to cognitive processing activities (e.g. problem-solving, decision making) and 2) directed to the acquired cognitive structures (e.g. mental models, types of knowledge).

Moreover, until nearly the year 2000, models of collective activities were a rather neglected area. The workplace, and the operator isolated in this workplace, were the dominant paradigms. When oriented to the collective aspects, studies were devoted to the normative allocation of tasks, and to the corresponding design of prescribed communication. This topic evolved rooted on Social-psychology oriented approaches grounded on the consideration of interactions in real professional groups, coping with real work situations spur numerous methods for teamwork design, analysis and evaluation and the consideration of new (collective) constructs that become units of analysis to cope with the interplay between individual and collective levels (Fiore, Smith-Jentsch, Salas, Warner, & Letsky, 2010).

Considered its original domains (aviation and critical industrial plants) HF tenets focused on human operator safety and enhanced performance. Literature is abundant on studies on human performance, error and overall reliability. Regardless the school of thought and line of work, the overwhelming acknowledgment is that human operator performance is inherently bounded by

a myriad of interwoven Performance Shaping Factors (PSFs) of individual, team, task, work context and organizational levels, pointing to a holistic, systems oriented approach to human performance analysis and evaluation (Hollnagel, 2000)(Dulac & Leveson, 2004)(Sun, Houssin, Renaud, & Gardoni, 2018). The exact structure, content and number of PSFs varies as a function of the aims scope, chosen methodology and the domain in question, but as a construct they hold intrinsic characteristics: 1) they may influence each other and work (performance) outcome, either positively, negatively or be neutral; 2) the boundaries of their levels and categories may overlap; 3) they may be more or less readily observed; 4) they may range from easily actionable (intervention) to extremely inaccessible; 5) they solely or (weighted) combined constitute/inform metrics, and; 6) they may hold different time dynamics

The collection of the data underlying PSFs analysis, evaluation and interventions design may be framed in HF methods as: 1) Methods for collecting data about people (e.g., collection of data on physical, physiological, and psychological capacities); 2) Methods used in system development (e.g., collection of data on current and proposed system design); 3) Methods to evaluate human-machine system performance (e.g., collection of data on quantitative and qualitative measures); 4) Methods to assess the demands and effects on people (e.g., collection of data on short-term and longer-term effects on the well-being of the person performing the tasks being analyzed) and 5) Methods used in the development of an ergonomics management program (e.g., strategies for supporting, managing, and evaluating sustainable ergonomics interventions) (Corlett, Wilson, & CORLETT, 1995)(N. Stanton, Hedge, Hendrick, Salas, & Brookhuis, 2004).

Inherently, HF research still currently faces some challenges: practical/feasible methods integration, grounded on the theoretical tenets, and delivering basis for informed suitable interventions.

### 3 Proposed Framework

Business Intelligence projects deliver reporting dashboards with filtering, visualization and analytical capabilities over business processes' measures, which are constituted from previously identified/selected, modelled and pre-processed raw data. Frameworks for BI endeavours, provide guidance through systematic practices and artefacts on the elicitation of data (and its sources) in order to become information in the form of a KPI. For instance, the Bus Matrix artefact (Kimball & Ross, 2002), allows to map which dimensions (according Kimball's dimensional modelling approach) participate in corresponding measures definition for each business process.

In the Business Intelligence for Human Factors (BI4HF) framework herein defined, it is proposed that either existing (business) measures or newly derived ones may be analysed through the lens of HF related dimensions for businesses or organizations with human operator in the operational loop. Figure 3 presents an integrative characterization of human operator within her/his operational work context. This characterization acknowledges several macro dimensions that bound operational operator's work as put forward by HF research.

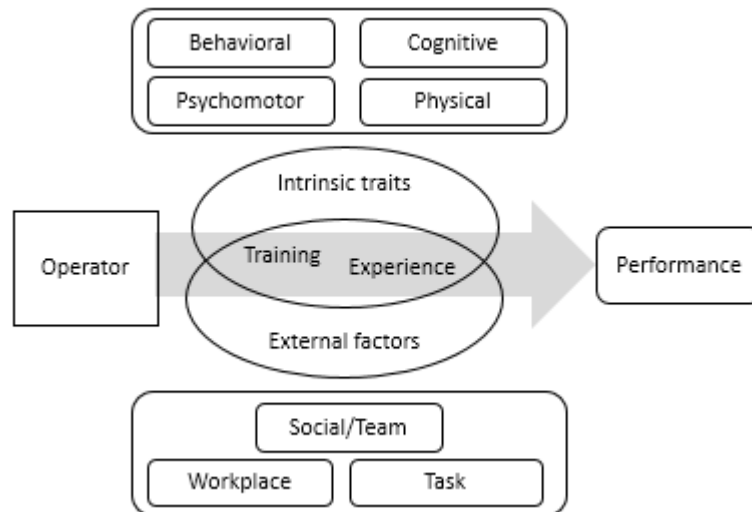


Figure 3 – Human Operator in work context characterization model

BI4HF distinguishes seven paramount macro dimensions to be attended according their nature. The first four in regard to intrinsic human traits: 1) cognitive, 2) behavioural, 3) psychomotor and 4) physical; while the second set of three come from externally (in regard to human operator) driven factors: 1) social-organizational/team, 2) workplace and 3) task.

One should make notice that the proposed macro dimensions for HF based analysis do not pretend to constitute an overly closed set and, as earlier discussed, multiple interplay between dimensions of each of the two sets may occur, and for specific domain and/or application other division/organization and further extension or confinement may reveal more appropriated. Nevertheless, the proposed formulation still holds its guidance value on furnishing data dimensional modelling for analytical purposes.

In order to account for the role of each of the macro dimensions, BI4HF provides directions to substantiate associated/derived dimensions of analysis. Toward that end macro dimensions are further divided down to enact proper dimensions of analysis each of which holding the attributes that grounds the analytical aims, Figure 4. Figure 5 presents the revision of the multi-dimensional modelling star schema conceptualization revised incorporating HF related dimensions of analysis to illustrate the overall vision of BI4HF.

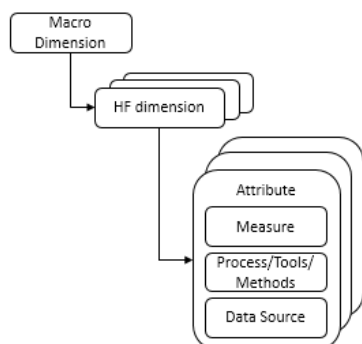


Figure 4 – HF dimensions and attributes derivation from Macro dimensions

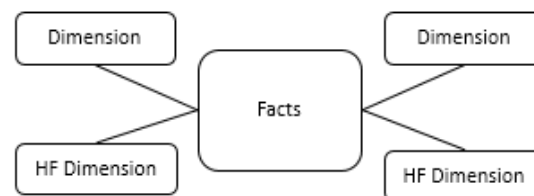


Figure 5 – Enriched multi-dimensional star-schema model

Dimensions of analysis on the realm of intrinsic traits and external factors macro dimensions, as well as, the interplay between them, had been addressed by organizations and research through two major paradigmatic lines of work.

Depending on the size and domain of activity some organizations (may be required to) recur to psychometric evaluations on HR recruitment and periodic reassessments (for training refreshing programs). On the other hand, HF research, fuelled by more critical industries/domains, build upon organizational psycho-sociology and socio-technical systems methods of analysis, have been delivering constructs and techniques to situated action fine grain understanding of human performance.

Pursuing indicators of alignment between human operator and job role to promote performance, psychometry rely on numerous tests/scales and structured task scenarios to elicit attributes that may constitute dimensions of analysis over Facts measures, provided an enhanced characterization of business process measure's context.

Clearly the concrete selection of such tests will be domain bounded, but examples of those are: aptitudes tests (e.g. on numerical, verbal, logical, abstract or diagrammatic reasoning); abilities and skills tests (e.g. learnability potential, psychomotor coordination, manual dexterity); (work) personality, and work style tests including team orientation potential (e.g. Myer-Briggs Type Indicator, DiSC Behavior Inventory or Working Styles Questionnaire (WSQ)).

Over another line of work, a taxonomic view on HF arena yield four complementary classes of assessment targets and techniques associated with the posited macro dimensions that bound performance: 1) (human operator) individual cognitive constructs, 2) individual internal processes developing/addressing individual constructs, 3) collective constructs and 4) external processes developing/addressing individual and collective constructs. Examples of individual cognitive constructs are mental models (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000), situation awareness (Endsley, 1995) or cognitive load (Young, Brookhuis, Wickens, & Hancock, 2014). Such constructs inform subsequent action and are kept up-to-date through internal unconscious and conscious processes regarding perception and vigilance, sensemaking (Weick, 2000) and planning and decision making (Klein, 2008). Collective constructs, as distributed cognition or macrocognition (Wallace & Hinsz, 2010) or distributed/shared situation awareness (N. A. Stanton et al., 2008), shift the unit of analysis acknowledging the distributed nature of work. Both individual and collective constructs couple with external processes as work artefacts interactions and team communication (modalities and patterns) and interactions (collaboration and coordination structures) (Kottemann, Boyer-Wright, Kincaid, & Davis, 2009)(Espinosa et al., 2000)(Liu, Nersessian, & Stasko, 2008)(Böhler, Neyer, & Moeslein, 2011). Several assessment techniques address the aforementioned constructs and processes, Table 2 summarizes some (most of presented ones may be directed to one or simultaneously inform more than one HF dimensions of analysis attributes), for details on many of these methods refer to (Patterson & Miller, 2012).

Table 1 – Examples of HF constructs and processes and assessment methods

	Examples	Assessment methods
Internal Individual Constructs	Mental models (on task, team, ...) Situation awareness Cognitive load	Cards sorting, Concept mapping, Comparison ratings, Scenario probes, Direct querying/questionnaires, Debriefs Contextual (experts) observation Eye tracking Think aloud protocols Workshops Focus groups Interactions analysis Work artefacts usage analysis Communications analysis Processes tracing
Internal Individual Processes	Attention management Action Planning Sense making Decision alternatives weighing Context screening	
Collective Constructs	Team mental models Team shared awareness Macro cognition	
External Processes	Coordination strategies Collaboration Negotiation Communication patterns	

Common to HF paradigmatic approach is the emphasis given to the operational context and situated action. Therefore, task, work artefacts and workplace characterization has been chiefly attended. Work processes/tasks' structure, dynamics and couplings, descriptive attributes elicitation may recur to, domains' standards (e.g. Methods-Time Measurement – MTM (Karger & Bayha, 1987)), or be directed by the phenomena of interest defining different granularity levels of socio-technical work process description (Jenkins, Stanton, & Walker, 2010).

Work artefacts and workplace ergonomics further constitute additional sources for dimensions of analysis formed by attributes expressing e.g. usability (McNamara & Kirakowski, 2006) or physical ergonomics (Alvarez-Casado, Colombini, & Occhipinti, 2013). Regarding a broader characterization of the workplace, one can borrow from some complex regulated domains concerns and extend analysis, when pertinent, toward local operational environment with the consideration of possibly stressors or performance shaping factors regarding conditions on lightning, temperature, noise and/or atmosphere (Vischer, 2007). Figure 6, depicts the interplay of these facets toward providing guidance on complementary definition of HF dimensions of analysis.



Figure 6 – Interplay between dimensions of analysis of Task and Workplace macro dimensions



## 4 Use Case

The use case herein reported refers to a business unit in manufacturing industry. The scope of the project was bounded to the operational level of work in the production lines.

The overall aim was to develop a fine grain understanding of the operational context in regard to minor product non-compliances related KPIs. Although not frequent since operational work presents a high level of standardization, human resources/operator are thoroughly recruited and trained and task and workplace are carefully designed; still, some KPIs exhibit that occasionally quality assurance detects, and have to promote correction, of minor non conformities.

The proposed BI4HF framework was used to complementary support pertinent data identification, data sources, processes for data collection and integration within a data warehouse multi-dimensional data model. These model provided analytical support toward browsing KPIs through the several attributes of the newly derived dimensions of analysis.

Through the data modelling endeavour multiple meetings, structured interviews and rating questionnaires involved stakeholders from several organizations' areas and departments. Table 2 summarizes the instances of BI4HF framework Macro dimensions, elicited to be considered under the project scope.

Currently, as project outcomes, an enriched multi-dimensional data model persisted through a relational star schema on a data warehouse integrates existing and new dimensions of analysis.

Facts tables are composed by several measures on non-compliances (e.g. extent, severity) that fuel several KPIs. It is now possible to browse addressed KPIs with multiple (possibly combined) filtering and aggregation criteria throw-out the majority (some are still not fully nurtured) of attributes of instantiated dimensions of analysis. The full derived analysis on those and respective operational conclusions to the addressed organization are beyond the scope of this paper, which main focus is on provide guidance on a holistic elicitation of dimensions of analysis with the consideration of HF realms and respective integration on multi-dimensional data modelling paradigm in BI endeavours. On that subject matters this use case provides evidence of BI4HF delivers.

## 5 Conclusions

With the ever growing storage and processing capacity and increasing availability, as supported by Gartner Magic Quadrant 2018 Report on BI technology, Business Intelligence endeavours main challenges tend to depart from technology related aspects and remain on the realm of data modelling. In fact, harmoniously integrating unstructured and structured data of different natures from disparate sources and report it as actionable information had been, and still is, one of the main workflows in a BI project. Typically business process defined measures inform several Key Performance Indicators (KPIs) delivered accordingly through the different levels of decision makers. These KPIs are often interpreted through the lens that operational level of work adhere to work processes specification. As also, browsing abilities to navigate through out the filtering and aggregation features over provided KPIs are also provided on that basis.

Table 2 - BI4HF framework Macro dimensions

Macro Dimension	Dimension of Analysis	Attributes	Attributes' values domain	Source of data
Individual – Demographics	Demographics	Gender, Age, Location, Education	Full filled Accordingly	Organizational databases
Individual – Cognition	Cognitive	Visual memory, Spatial reasoning, Decision profile, Focused attention	Scores on each attribute	WSSP tests WSSD tests
Individual – Behavioural	Personality	Thinking Style	Scores on: Practical, Innovative, Adaptable, Forward thinking, Detail Conscious	WSQ tests
		Energy	Scores on: Active, Competitive, Achieving, Decisive	
		Compliance	Scores on: Dependable, Social desirability	
		Feelings and Emotions	Scores on: Resilient, emotionally controlled, Optimistic	
Individual – Behavioural / Team	Team Orientation	Relationships with others	Scores on: Assertiveness, Self Confidence, Team Orientation, Considerate	WSSD tests
Individual – Psychomotor	Psychomotor coordination	Visual motor coordination, Fine manual dexterity	Scores on each attribute	
Task	Work process	Process subtasks' types	# of subtasks by type	Organization's work process definition
		Sequencing	# of disparate subtasks' types	
		Timing	Cycle time	
		Manipulated pieces	# of parts involved	
Task - Individual	Training	Type	# of training programs by type	Organizational databases Organizational databases
		Duration	Total of hours of each training type	
		Date	Last date of each training type	
	Experience	Seniority on job	Time by job type	
		Versatility	# of jobs ready to perform	
Workplace	Tools	Number of tools	# of tools to manipulate	Organization's work process definition
	Ergonomics	Position	Scores on each	According organization adopted standard
		Effort		
		Movement		

For contexts with human operator in the operational work level where actual practice may contrast/depart with/from formal work specifications, a broader characterization of the context that fuelled the KPIs may inform a finer grain understanding on business metrics, imposing additional data modelling requirements.

The work in the Human Factors arena, fuelled by both critical industries' domains and complex organizational socio-technical systems, had early departed from the narrow vision of human error aetiology toward the recognition of the human performance within the broader work/organization system that she/he integrates (Rasmussen, 1997)(Reason, 2000).

This work borrows the HF perspective to furnish data modelling underlying BI projects addressing organizations where the accountability of HF related dimensions of analysis may reveal pertinent on a further understanding of business processes measures.

Rooted on the multi-dimensional data modelling envisioned by Richard Kimball BI framework (Kimball & Ross, 2002), this work proposes a Business Intelligence for Human Factors – BI4HF framework to provide guidance on the integration of HF related dimensions of analysis in the data modelling workflow of BI projects. The proposed framework is heavily grounded on the theoretical body of work of HF literature. The BI4HF has been applied on a BI project in a manufacturing industry organization and lead to the development of new analytical capabilities on newly derived and existing KPIs. Further work remains to be done on providing BI4HF companion artefacts for enhanced guidance on combining HF measures and methods with features and requirements specification on BI projects' scope.

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